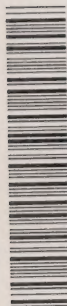


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THE MANUFACTURING RESEARCH  
CORPORATION OF ONTARIO




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## 1989-90 REPORT



CENTRE OF EXCELLENCE SUPPORTED BY  
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## MISSION STATEMENT

Increasing global competition was the central factor governing the formation of The Manufacturing Research Corporation of Ontario (MRCO); one of the seven Centres of Excellence designated by the Premier's Council.

As technological change is key to the attainment of long-term economic growth and success, MRCO's primary objective is to facilitate and cultivate Ontario's university-based fundamental research projects which have industrial relevance. These projects relate mainly to manufac-

turing automation, design, management and processes. Our second, equally important mandate is the promotion of technology transfer to industry. This second part of our mission will be implemented through the Industrial Participation Program, employing either Consortia or the direct approach.

In accomplishing our mission, MRCO will assist the province's manufacturers in facing the challenges of a dynamic and competitive marketplace.

## TABLE OF CONTENTS

Chairman's Report .....	2	Appendix 1:	
Board of Directors .....	3	Executive Summary of Scientific	
President's Report .....	4	and Industry Advisory Committee	
Research Projects		Report .....	15
Introduction .....	6	Finance Committee .....	15
Automation .....	7	Executive Committee .....	15
Design .....	9	Appendix 2:	
Management .....	11	Senior Advisory Committee .....	16
Process .....	13	Appendix 3:	
		Research Expenditure Report .....	17
		Appendix 4:	
		Annual Audited Financial Statements .....	20

### FRONT COVER

At the Lake Erie Works caster's tundish level, skilled operators preside over the smooth, even flow of hot steel into an oscillating water-cooled mould.

*The interior pages of this report are printed on recycled paper containing at least 50% post consumer waste. To facilitate further recycling on disposal, please separate the recyclable interior stock from the non-recyclable cover.*

## CHAIRMAN'S REPORT

**T**he Manufacturing Research Corporation of Ontario (MRCO), one of Ontario's seven centres of excellence, completed its second successful year of operation.

During the past year, MRCO's governing body, the Board of Directors, experienced some change. Dr. Art Heidebrecht, formerly Dean of Engineering at McMaster University, and Dr. Jim Retallack, Assistant Vice President of Manufacturing at Northern Telecom Canada, have undertaken new assignments, necessitating their departure from the Board. I would like to thank these gentlemen for their participation and the guidance they provided during our initial years. I would also like to welcome the new members of the Board: Dr. Ron Childs, Vice President of Research at McMaster University and Mr. Keith Powell, Director of Manufacturing at Northern Telecom. (The Board of Directors is listed at the end of the Chairman's Report.)

MRCO continues to operate with its mandate of:

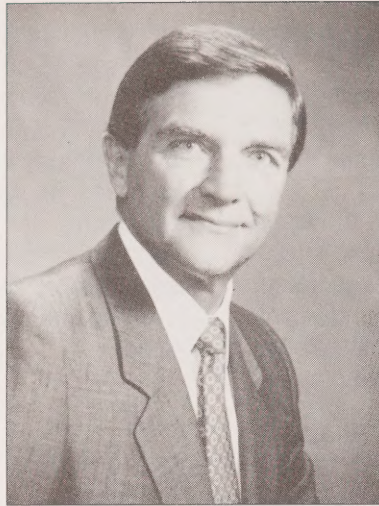
- administering and monitoring manufacturing research at Ontario universities;
- facilitating the transfer of this research to Ontario industries;
- enhancing industry-university relations.

MRCO continues to build on its primary objective of supporting advanced manufacturing research at Ontario's universities.

During the fiscal year 1989-1990, MRCO's research program consisted of fifty-two research projects at six Ontario universities. The projects were directed by thirty-one principal researchers who were supported by fifty-three associated researchers.

Funds allocated by MRCO for the research program totalled \$5.2 million and supported projects ranging from "Computer-Aided Process Engineering" to "Intelligent and Flexible Automation Systems".

Only two of the research projects undertaken in 1989 did not meet or exceed the strict quality



*J. E. Urbanic, Chairman*

performance criteria established by MRCO's "Peer Review System", with the Scientific and Industrial Advisory Committee. The funds originally allocated to these cancelled projects were redistributed for use in other research projects.

Over the past year, one of MRCO's strategic initiatives was to build a network to increase the awareness and expand the involvement of industrial participation in university research activities. Senior managers at three hundred small and medium-sized Ontario companies were contacted to promote better

communications between Industry and the universities conducting research. Of the target companies surveyed, one hundred and seventy-four expressed interest in further exploring the opportunities and benefits available to them from the applied research projects. As a result, sixty-two projects are now in the tendering stage and twenty-five projects were accepted and are at a functional stage involving researchers from Carleton, McMaster, Queen's Universities, the Universities of Toronto, Waterloo and Western Ontario. In addition, Ryerson Polytechnical Institute has recently been added to our academic pool.

The projects currently under study with various individual firms relate to metal forming, chemical processing, plant design, waste management and manufacturing systems. It is anticipated that six of the present research projects under review will become commercially productive this year, providing the immediate benefit of reduced manufacturing costs to the respective companies involved. Furthermore, MRCO has established a goal of acquiring an additional fifty direct manufacturing technology contracts in 1990.

During 1989, MRCO added a Consortia Manager, Mr. Christopher Beaver, and implemented the consortia services that were in the planning stage in 1988.

The first consortium, the Foundry Group, grew out of a CAD system developed by Dr. John Goldak from Carleton University. It united ten iron

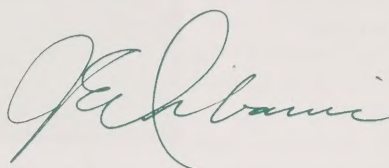
foundries that shared the common goal of improving casting design and methodology. The second consortium, FORMTECH, is a joint venture between ten of Ontario's major steel and metal stamping companies and the Province of Ontario. An addition to consortia services is the Canadian Die Cast Group. Its goal is to assist Canadian companies in the use of computer-aided design and manufacturing (CAD/CAM) techniques to enhance productivity in the manufacturing industry. The Supplier Consortium is the most recent initiative. The objective of this group is to reduce input costs to the manufacturer.

MRCO intends to further facilitate the formation of additional consortia in 1990 in the areas of plating, welding, food processing, paving, electronics and process control.

In an effort to further enhance industry-university relations, MRCO sponsored its first conference. The two-day affair was held in Orillia and brought together 120 professors and students to network, share ideas and review the four key areas of research identified as Automation, Product Equipment and Facility Design, Manufacturing Management Systems and Manufacturing Processes.

As we enter the next decade, MRCO expects industrial environmental issues to become a major focus for expansion in our fundamental research program. MRCO hopes to play an increasingly important role interfacing between universities and industry in the application of new technologies within the manufacturing community. In its effort to prepare for an increasingly technological world, continued support is required to ensure Ontario remains competitive in today's global market.

Once again, the Board of Directors of the Manufacturing Research Corporation of Ontario wish to extend a sincere thank you to the provincial government for their ongoing support.



J.E. Urbanic  
Chairman

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## Manufacturing Research Corporation of Ontario

### Board of Directors 1989/90

Mr. John Urbanic (Chairman)  
Director Car & Truck Assembly  
Operations  
General Motors

Mr. Fred R. Beaman  
Senior Vice President  
Canadian Manufacturers' Association  
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Dr. Clare Beingessner  
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Dr. Ron Childs  
Vice President Research  
McMaster University

Mr. Ed Dyson  
President  
Manufacturing Research Corporation of  
Ontario (MRCO)

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Mr. William J. McClean  
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Dr. Les C. McLean  
Vice-President of Quality &  
Technology  
Stelco Inc.

Mr. Keith I. Powell  
Director, Manufacturing  
Northern Telecom Canada Ltd.

## PRESIDENT'S REPORT

**T**he Manufacturing Research Corporation of Ontario's Annual Operating Plan for 1989 identified three essential activities which would help us to accomplish our mission. These involve fundamental university research, the Industrial Participation Program and an extensive communications plan. We have targeted four key fields of manufacturing-related research:

- Automation
- Design
- Management
- Process

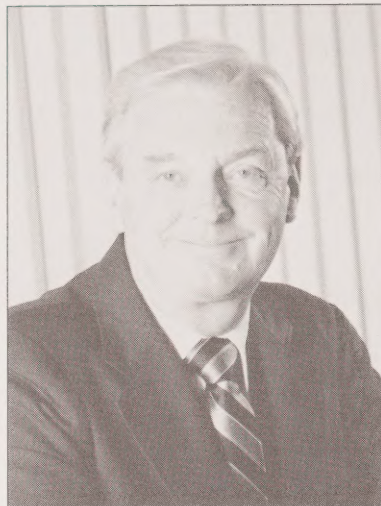
Funding in 1989/90 supported 31 Principal Investigators managing 37 budgets, which relate to 52 research projects being conducted at six Ontario universities. These projects fully meet the university criteria for "fundamental" research, and are intended to produce industry-relevant technological advances. The Principal Investigators conducting these projects are located at the following six universities:

- Carleton University
- McMaster University
- Queen's University
- University of Toronto
- University of Waterloo
- University of Western Ontario

MRCO closely monitors these projects to ensure that they are progressing as planned.

Leading industrialists from General Motors, IBM and Northern Telecom, senior engineering researchers from McMaster, Waterloo and the University of Toronto, and MRCO's President and Executive Vice-President form the Senior Advisory Committee (Appendix 2). The Committee meets monthly, providing valuable assistance to MRCO management in the execution of Board directives. Committee members constitute a vital link to their respective communities.

MRCO's activities are further supported by the Finance Committee and the Executive Committee of the Board (Appendix 1). During 1989/90, we saw two changes to our Board of



*Mr. E.A. Dyson, President*

Directors. We would like to extend our sincere thanks and best wishes to Dr. Art Heidebrecht of McMaster University and Dr. Jim Retallack of Northern Telecom Canada Ltd., who have left to assume new assignments. Please refer to the Chairman's Report for a current Board of Directors listing.

MRCO maintains regular, close contact with all Principal Investigators. It is our goal to support those projects useful to industry. This is accomplished by the following means:

- encouraging the generation of published data that results from fundamental research;
- identifying technical developments that are relevant to industry;
- actively promoting the transfer of technology.

The Scientific and Industry Advisory Committee (SIAC) is composed of 16 internationally recognized technical experts. This Committee is organized into teams of 3 (2 academics and 1 industrial member). Each team reviews the annual project reports developed by our researchers and provides an unbiased evaluation based on their review. This guarantees that MRCO's portfolio of research projects meets world-class standards and maintains industrial relevance. Projects requiring modification or not meeting expectations are also identified by the SIAC team.

The majority of the projects reviewed in 1989/90 yielded fully satisfactory results. Following consideration of all evaluations, a recommendation was made to discontinue two projects. Additional data on the Scientific and Industry Advisory Committee Report may be found in Appendix 1.

This year, MRCO funds supported an academic research team of 363. The team was led by a total of 84 professors (principal investigators and their associates) (Appendix 3). Specific mention should also be made of the 160 students at graduate level, a full 12.6% increase over last year. Our enthusiasm continues to grow, as the number of graduate students steadily increases.

MRCO's head office is now administered by 6 full-time and 2 part-time staff. The increase in head office staff is largely due to the development of our Consortia program.

The Industrial Participation Program consists of two approaches – Consortia and the Direct Approach. MRCO's Industrial Participation sales personnel possess a wealth of manufacturing experience. They ably promote industry-university linkages via a direct, one-on-one approach. Twenty-five "direct approach" projects were initiated in 1989. Unlike consortia, each company paid to develop a solution to its own need, thereby improving its own performance. It is evident from this progress that MRCO programs are effectively breaking down industry's apprehension toward university-based research. Such facilitation of technological change will definitely enhance Ontario's capability to compete in the global market.

The opportunity for consortia was developed during the last half of 1989, from the work of Dr. John Goldak of Carleton University. The consortia approach delivers a significant, collective return on investment, as many organizations contribute to projects that answer a shared need. It allows small organizations to cost-effectively develop, improve and refine their manufacturing skills. MRCO serves on each consortium as an ardent guide, providing an impartial, yet informed link between industry, technical resources, academia and government.

A total of four consortia are presently functional and another four are in the planning stages.

The Industrial Participation Program has certainly helped smaller firms recognize the worthiness of university research and research students. Major renovations to the mining building at the University of Toronto also bears witness to our joint interest in the manufacturing-academia liaison.

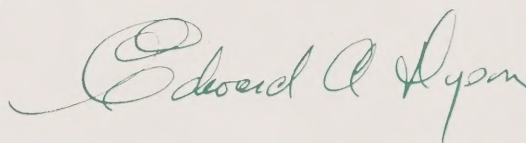
Communication is essential to the continued growth and success of MRCO's programs. Creating awareness and providing a forum for government, industry and research interaction constitute the primary goals of the communications plan. This year we have produced new

material to be distributed with our corporate brochure. This includes information on our Board of Directors and ten separate case histories. Presentation materials in the form of slides and overheads are continually being updated.

A multi-media approach has been employed to reach Industry and academia with the MRCO message. Industry releases are regularly dispatched. Seminar and workshop sponsorship, participation in trade shows and open houses, and monthly presentations by MRCO management have also increased our visibility. MRCO's contribution to Ontario's future economic success has been covered by the press, with articles appearing in *The Globe & Mail*. Stelco also featured a most supportive article on MRCO, in its own newsletter, *Stelco Today*.

MRCO, through its researchers at McMaster and Western University, is co-operating with the Fraunhofer Institute on an Ontario/Baden-Wurtemberg research program. The focus of this research should benefit small to medium-sized manufacturing firms in implementing Computer-Integrated Manufacturing (CIM).

Technological change is key to Ontario's long-term economic health. The Manufacturing Research Corporation of Ontario intends to be a positive force in helping propel Ontario industry into the mainstream of the world market. We will meet our objectives by helping manufacturers improve their competitive position in the years to come. The successful launch of our Consortia program and the Baden-Wurtemberg collaboration illustrate our commitment to our mission. Such dynamic growth in our Industry-university linkages will ensure our continued success.



E.A. Dyson  
President

## INTRODUCTION TO THE RESEARCH PROGRAM

**D**uring the fiscal year 1989/90, MRCO's research program consisted of 52 research projects at 6 Ontario universities. The projects were directed by 31 principal investigators and supported by 53 associated researchers. Five of the principal investigators directed two or more projects. There were 37 project budgets distributed as follows:

McMaster University	9
University of Toronto	9
Queen's University	3
Carleton University	1
University of Western Ontario	1
University of Waterloo	14

A total of 160 graduate students received financial support during 1989. MRCO maintains a strategy of supporting Ontario's recognized, leading academic researchers, whose work will clearly benefit the industrial manufacturing sector.

MRCO funding enhances all projects by supplying capital and supporting manpower. This is evidenced by a marked increase in the number of graduate students involved in these programs. It is through human resources that technology will be most effectively transferred. Many MRCO-funded graduates are or will be employed by industry, where they can positively influence manufacturing proficiency.

## Focus

Industrial automation involves "product design", "process planning", and "production". CIM (Computer-Integrated Manufacturing), a new paradigm, promotes the integration of manufacturing functions, information flow, CIM components, and all planning aspects of the enterprise. Integration of the various stages in the manufacturing cycle and effective cross-communications are also essential to automation.

Central concepts include: creative design, group technology, concurrent engineering, design and tolerancing for manufacturing, CAD/CAM integration, and closed-loop process planning/manufacturing planning and control. The following technologies play a key role in industrial automation: Artificial Intelligence, Artificial Neural Networks, Information Technology, Sensors, Robotics, CNC, and Autonomous Manufacturing Tools.

## Highlights

Activities at McMaster's Manufacturing Automation and Control Laboratory, where MRCO supports research in robotic machining, are supervised by Dr. Mohamed Elbestawi. With

the help of MRCO, specific industrial applications with potentially high market demand have been targeted for robotic automation. Grinding and deburring are the two machining processes for which quality and productivity are being enhanced.

Advanced, sensor-based control strategies provide the foundation for all modern industrial automation and require detailed knowledge of both the machine and the process it performs. Both deburring and grinding are very complex cutting processes which change with time. The McMaster team studied the dynamics of these processes. Their efforts resulted in the development of mathematical models, which are being used to control the processes. Because the dynamics of these processes change due to factors such as tool wear and variable robot stiffness, the models must also change. Successful implementation of real-time modelling (parameter estimation) and adaptive control provided the robots with more intelligence to effectively address these variables.

Increasing the intelligence of the robotic system to more closely approach the skill of a human operator is handled by providing it with the capability to do task planning. In grinding, for example, the sophisticated model of the process allows accurate prediction of the outcome of a series of



*A graduate student at McMaster University is manipulating the operations of a forced controlled robotic grinder.*

grinding passes. The controller can, with a large degree of certainty, optimize the grinding sequence for the number of passes and cutting conditions to achieve the desired final profile. Consequently, task planning, formerly consisting mostly of guesswork by a human operator, can now be performed with a high degree of accuracy.

Many of today's machining processes require tool positioning accuracies beyond the capabilities of current industrial robots. According to Dr. Elbestawi, a significant percentage of future generations of machining robots will employ active-end effectors, or highly accurate, high speed "micro robots" at the business end of larger, less accurate robot manipulators. This concept has been implemented with great success on a PUMA 560 robot to increase its positioning accuracy tenfold for deburring. This technology is also finding its place in many other manufacturing applications.

## Research Projects

The Automation theme of research consists of 14 projects at 4 universities directed by 7 Principal Investigators. The projects in Automation during the 1989/90 year were:

### McMaster University

- A) Sensor control for industrial robots.  
– M.A. Elbestawi
- B) Intelligent and flexible automation:
  - a) Generative, knowledge-based planning of manufacturing tasks.
  - b) Robot assembly assisted by force and tactile sensing.
  - c) Design and evaluation tools for flex manufacturing.
  - d) Universal and flex tooling for flex assembly.  
– H. ElMaraghy

### Queen's University

- A) Distributed multi-sensory multi-processor control hierarchy and algorithms.  
– M.M. Bayoumi
- B) Integrated tactile and visual perception for robotics.  
– R. Browne
- C) Designing an intelligent tactual perception system for sensate robotics application of models of human tactual exploration and recognition of objects.  
– S.J. Lederman

### University of Toronto

- A) An experimental automatic assembly workcell – research development and integration.  
Analysis and design of industrial robots – multi-arm manipulators and modular manipulators.  
– B. Benhabib
- B) Development of controlled techniques for robotic systems.  
Techniques for robotic systems.  
Development of control techniques for process control.  
– E.J. Davison
- C) Robot structural and deflection analysis, design, optimization and performance evaluation.  
– R.G. Fenton
- D) Uncertain geometry in off-line robot planning.  
Design dynamics and control of multi-fingered dexterous hands  
– A.A. Goldenberg
- E) Sensors and sensor-emphasizing preconditioning.  
– K.C. Smith

### University of Waterloo

- A) Production scheduling and design for assembly of electronic circuit boards.  
– T. Vanelli
- B) Design and control of lightweight robots/off-line optimal path planning.  
– M. Vidyasagar
- C) Sensor integration for direct end-point control of robot manipulators.  
– W.J. Wilson
- D) Sensor knowledge-based intelligent manufacturing.  
– A. Wong

### Focus

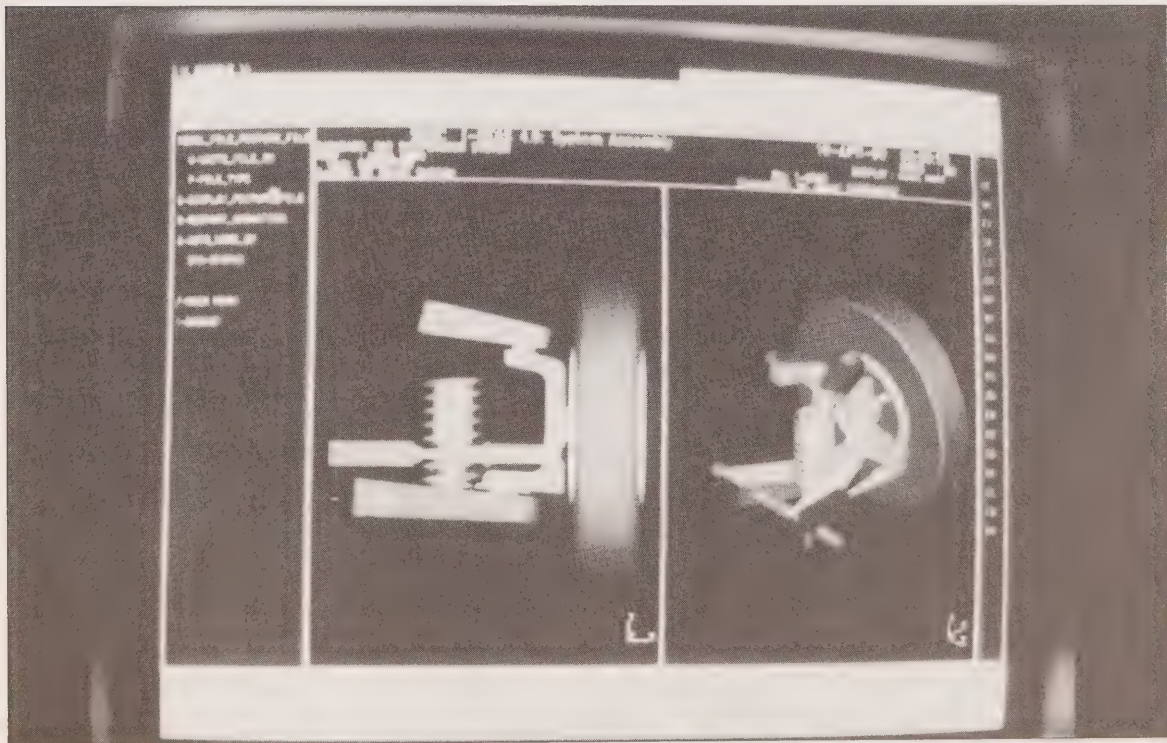
**D**esign for manufacturing involves the integration of software development for manufacturing processes and products with actual product design and analysis techniques.

### Highlights

Dr. Waguih H. ElMaraghy has been an MRCO Principal Investigator for three years – working from the University of Western Ontario's Design, Automation and Manufacturing Research Laboratory in Engineering Science. His teaching and research interests include CAD/CAM, CIM, and mechanics and multi-body system dynamics and robotics. Dr. ElMaraghy's work in the latter area resulted in the development of SYSBOND – software which presents an interesting opportunity to the industrial designer.

SYSBOND is a suite of programs for the modelling and analysis of the kinematic and dynamic behaviour of planar and spacial mechanical systems. SYSBOND uses the bond graph method for representing the physical model. Analysis work is performed by ACSL (Advanced Continuous Simulation Language), which models systems described by time dependent, non-linear differential equations. The program runs on Sun work stations under SunView. The implementation is capable of using large models and showing all parts of the process at one time, due to its multi-window, multi-tasking environment.

The current interest in multi-body system dynamics (MBSD), can be compared to the interest in finite element methods (FEM) research in the 1960s and 70s. Similar to Finite Element Analysis programs which have now become a standard tool in structural analysis and design, a general multi-body system dynamics formulation is a useful tool for the study of motion dynamics of many mechanical systems.



*The above photograph is an example of Feature-Based Modelling and Design. Its function is to capture both the geometric and technical knowledge and share this knowledge with subsequent manufacturing tasks planning. The underlying concept is to facilitate simultaneous engineering activities with functional manufacturing decisions.*

A wide variety of such systems can be modelled, including planar mechanisms, ground and aerospace vehicles, robots, bio-mechanical systems, legged vehicles, and systems with feedback controllers.

SYSBOND consists of three major parts, plus two utility parts (help, and file manipulation). The major parts are: Bond graph modeller, the Physical system modeller, and the Calculations or Results.

The modelling of the physical system (using masses, velocities, springs, friction, etc.) allows the user to quickly model a mechanical system using icons. From this model the bond graph model can automatically be generated. To do this, SYSBOND requires a degree-of-freedom specification, and a set of velocity transformations for every body in the representation.

The Bond graph modeller, can be used directly, or take its input from the Physical system modeller. This representation is based on a graph, i.e., a collection of nodes connected by arcs, representing bonds. The nodes consist of junctions, transformers, gyrators, effort and flow sources, etc. The Bond graph modeller, can automatically assign causality, power flows, and create an ACSL data file for execution.

## Research Projects

The Design theme area of research consists of 9 projects at 5 universities which are staffed by 9 Principal Investigators. The following are those projects in Design supported by MRCO during the 1989/90 year:

### Carleton University

- A) Feature-based design of castings.  
– J. Goldak

### McMaster University

- A) Software optimization of CIM procedure.  
– M.A. Dokanish
- B) Feature-based modelling and design.  
– H. ElMaraghy
- C) Integration of design of jigs and fixtures into design and manufacturing processes.  
– W.R. Newcombe

### University of Toronto

- A) Software optimization of CIM procedure.  
– W.B. Johnson/ S. Meguid

NOTE: Professor Johnson left University of Toronto in the second quarter. He was replaced by Professor S. Meguid.

### University of Waterloo

- A) Integration of solid modelling and kinematic dynamic analysis.  
– G.C. Andrews
- B) Development of raster-based CAD algorithms for drawing management systems.  
– R.J. Pick
- C) Thermo-fluid CAD and optimization for integrated manufacturing.  
– M. Yovanovich

### University of Western Ontario

- A) Modelling and design of multi-body machinery robots.  
– W. ElMaraghy

## MANUFACTURING MANAGEMENT

### Focus

**M**anufacturing Management professors conduct research relating to efficient plant management, including inventory control, quality control, material flow, plant lay-out optimization, simulation and scheduling.

### Highlights

The emergence of a new mathematical tool related to probability theory has exciting implications for manufacturers. Professor Turksen, in his MRCO project "Knowledge-based Management Systems for Integrated Manufacturing," applies the "new" Fuzzy Logic theory. In the Western world, we generally accept that precise information is available and that models describing operations and performance of manufacturing systems can be accurately developed. However, management of technology in Ontario does not really differ from the rest of the world. Humans use soft or Fuzzy Thinking daily with great success, e.g., just a little further, slightly to the left, one or two revs, etc. Recently, the number of

proponents of Fuzzy Thinking has grown. They argue that striving for exactness or precision in control of systems is unnecessary, expensive and may never be achieved. Since the real world gets along very well using approximate reasoning, why not seek to adapt it to systems management?

The father of Fuzzy Thinking, Dr. Zadeh (Professor of Computer Science and Electrical Engineering at Berkeley), developed the concept in the 1960s. General response was predictable. The Japanese however, unfettered by the strictness of Western thinking, agreed with Zadeh. The number of examples of consumer products operating on Fuzzy Logic principles demonstrate that the use of gradual or qualified statements can be more effective in solving programming problems. Examples of products developed on Fuzzy Logic principles and brought to market (in Japan) include: subway system control, Nissan's anti-skid breaking systems, a continuously variable transmission (Subaru) and an automatic washing machine that chooses 1 of 600 washing cycles to produce the cleanest wash!



*From left to right – Professor Turksen, University of Toronto, Professor L.A. Zadeh, founder of Fuzzy Thinking and E.A. Dyson, President of MRCO, take a moment together to pose for a photograph at the NAFIPS '90 Conference. This event celebrated a quarter century of Fuzziness.*

Professor Turksen centres his work on fuzzy sets and logic, and their dissemination for industrial applications. His primary expertise is in Approximate Reasoning, with particular applications in Production Planning, Scheduling and Inventory Control. His research has made him an internationally recognized authority on fuzzy logic based approximate reasoning. His recent work on the design of an electronic chip to process fuzzy inference algorithms is expected to open up a new window of opportunity for North American manufacturers to catch-up with the Japanese.

## Research Projects

The Management theme of research consists of 6 projects at 3 universities, staffed by 6 Principal Investigators. Following are those projects in Management which were supported during the 1989/90 year:

### McMaster University

- A) Management of integrated manufacturing systems. Integrated models and data for manufacturing, planning, optimization and control. Modelling and implementation/ advanced manufacturing systems.  
– J. Miltenberg/D. Montazemi

### University of Toronto

- A) Statistical methods for product design. Production planning and scheduling.  
– S.P. Sethi
- B) Knowledge-based management systems for integrated manufacturing.  
– I.B. Turksen

### University of Waterloo

- A) Planning and scheduling under uncertainty. Integrated models and data. Modelling and implementation of advanced manufacturing systems.  
– J. Buzacott
- B) Analysis and control of warranty claims and reliability problems.  
– J.F. Lawless
- C) Implementation and analysis of statistically designed experiments in manufacturing.  
– C.J. Wu

# MANUFACTURING PROCESS

## Focus

**P**rocesses in the manufacturing environment examine new methods of reducing costs related to processing technology in all material areas, such as chemicals, plastics, polymers, metal cutting and forming, welding and assembly.

## Highlights

The development of a robotic system for Gas Metal Arc (GMA) welding, one of the significant manufacturing process projects currently underway, will permit the real-time control of both robot and welding conditions. The successful completion of such a system will increase welding productivity for a wide range of applications. This project involves several faculty members at the University of Waterloo – Professors Hugh Kerr, Sanjeev Bedi, Jan Huissoon and David Weckman – since it is highly interdisciplinary and has several sub-projects. An object modeller has been developed for complex surfaces, permitting surface intersection routines which can be downloaded to the robot controller. A finite element model has been written which permits the prediction of weld shape, given the welding process

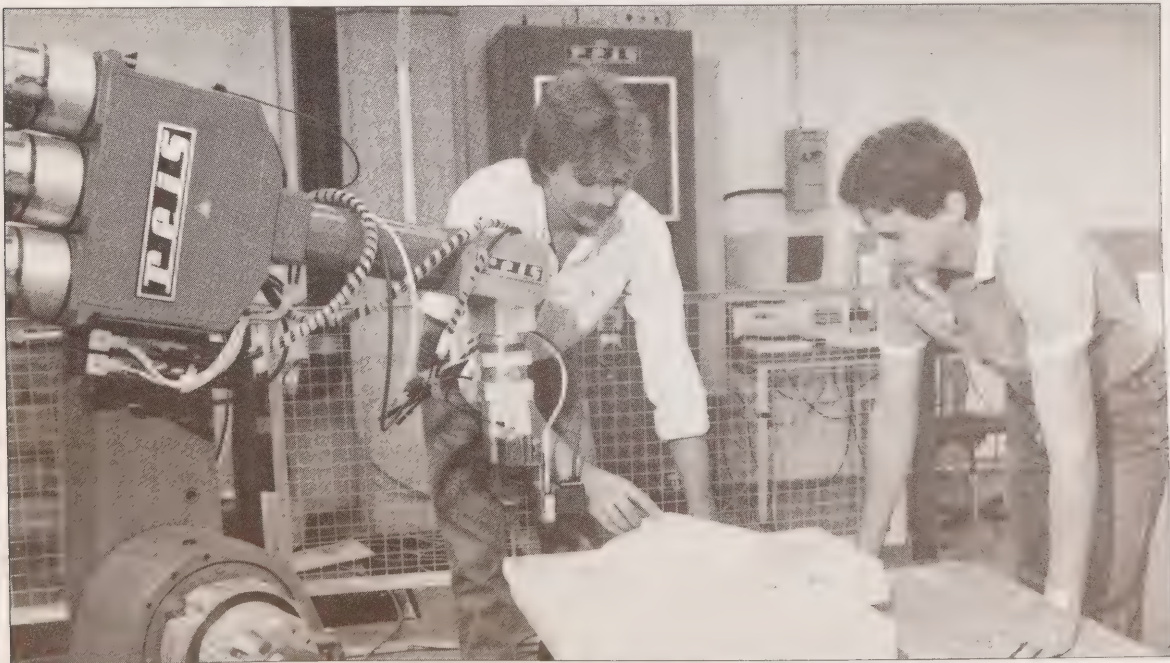
parameters. A new controller has been installed in a six-axis robot, permitting its end effector to be controlled in real-time, using input from a laser-based seam tracking system. A CCD camera, sensitive to infrared wavelengths, is used to sense the weld dimensions. This input will be used to control the weld process conditions; various control strategies are being considered for different types of welded joints. Increased interaction with industry interested in aspects of this project will be facilitated by the recent addition of a research engineer.

## Research Projects

The Processes theme area of research consists of 8 projects at 3 universities, led by 9 Principal Investigators. The following projects in Processes were supported during the 1989/90 year:

### McMaster University

- A) Limits, control and optimization of manufacturing processes:
  - a) Process planning and management control strategies.
  - b) New sensory feedback for new controller design.



*Professor Jan Huissoon and student Dave Strauss discuss the modified 6 axis robot and seam tracker used to follow complex three dimensional shapes in realtime, for application in robotic welding.*

- c) Adoption control in metal cutting using machine vision.
- d) Development of vision-based intelligent machine tool controller.  
– M.A. Elbestawi
- B) Development of steels with improved machinability.  
– A. Kay
- C) Modelling of metal deformation process.  
– R. Sowerby

#### **University of Toronto**

- A) Manufacturing of ordered polymeric profiles by extrusion drawing.  
– R.T. Woodhams

#### **University of Waterloo**

- A) Welding automation.  
– H.W. Kerr
- B) Detection of vibration/chattering:
  - a) Application of kurtosis method for early detection of machinery gear wear.
  - b) On-line monitoring of machinery processes.  
– H.R. Martin/ F. Ismail
- C) Tribological aspects of metal forming.  
– J.A. Schey
- D) Computer-aided process engineering:
  - a) Project synthesis.
  - b) Process control.
  - c) Process scheduling.
  - d) Expert systems.  
– G.R. Sullivan

## APPENDIX 1

### Executive Summary

#### Scientific and Industry Advisory Committee Report

**T**he objectives of the MRCO university research program include: an increased number of students graduating with advanced degrees, good quality academic publications and the transfer of technological advances – products of the program – into the manufacturing sector.

The Science and Industry Advisory Committee has the annual task of conducting a peer review to assess the quality of the Research and Development program. Their criteria are: quality of the researcher, quality of the project, its progress, its plan, and industrial relevance. In conducting the task, the 12 academic and 4 industrial members were organized into 4 teams of 3 (2 academic members, and 1 industrial).

Each was supplied with comprehensive “annual reports” prepared by each of the Principal Investigators. The report included up-dated resumes, accomplishments and awards, a work plan and budget request for the new year.

Of the 50 projects reviewed by the Committee, 12 were subjected to further follow-up with Principal Investigator interviews. Two were cancelled.

The quality of MRCO's Research and Development portfolio remains high. This type of external evaluation process may raise issues that are not made obvious by regular daily interaction. The process is also valuable as it leads to the clarification and accomplishment of goals. SIAC involvement simplifies the industry/academic interface, promotes a better understanding of industrial relevance and improves the likelihood of a successful transfer of the technology to an industrial partner.

### Manufacturing Research Corporation of Ontario

#### Sub-Committees

1989/90

##### Finance Committee

Dr. Michael Charles  
Vice-Dean of Faculty of Applied Science  
and Engineering  
University of Toronto

Dr. Les C. McLean  
Vice-President of Quality & Technology  
Stelco Inc.

Dr. Clare Beingessner  
Vice President, Engineering  
B & W Heat Treating (1975) Limited

##### Executive Committee

Mr. John Urbanic (Chairman)  
Director, Car & Truck Assembly  
Operations  
General Motors of Canada

Mr. William J. McClean  
Vice President of Manufacturing  
and Development  
IBM Canada Limited

Dr. Michael Charles  
Vice-Dean of Faculty of Applied  
Science and Engineering  
University of Toronto

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## APPENDIX 2

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### Manufacturing Research Corporation of Ontario

#### Senior Advisory Committee 1989/90

Mr. Edward Dyson (Chairman)  
President  
MRCO

Dr. Ross Judd  
Professor of Mechanical Engineering  
McMaster University

Mr. Michael Brothers  
Mgr. of ADC Product Planning  
IBM Canada Ltd.

Dr. Ron Venter  
Chairman of Mechanical Engineering  
University of Toronto

Mr. Peter Hartwell  
Manager, Advance Manufacturing  
General Motors of Canada

Mr. Ed Cinits  
University Representative  
MRCO

Mr. Mike Moorcroft  
Director, Manufacturing Technology  
Northern Telecom Canada

Mr. David Henderson  
Executive Vice President  
University Relations  
MRCO

Dr. David Dilts  
Director  
Waterloo Centre for Integrated  
Manufacturing  
(WATCIM)

## APPENDIX 3

### Manufacturing Research Corporation of Ontario

### Research Expenditures Report

Year Ended 31/03/90

University	Researcher	Theme	Expenses	Project Title
1) <b>Western</b>	ElMaraghy, W.	Design	\$ 140,595	Modelling/Design of Multibody Machinery Robots.
		TOTAL:	<u>\$ 140,595</u>	
2) <b>McMaster</b>	ElMaraghy, H.	Automation	\$ 231,382	Intelligent and Flexible Automation.
		Design	\$ 154,695	Feature-Based Modelling/Design.
	Elbestawi, M.	Automation	\$ 98,526	Sensor Ctrl. for Indust. Robots. Limits, Ctrl. and Optimization of Manufacturing Process.
		Processes	\$ 328,078	
	Kay, A.	Processes	\$ 205,368	Development of Steels with Improved Machinability.
	Sowerby, R.	Processes	\$ 229,459	Modelling of Metal Deformation Process.
	Miltenberg J.	Management	\$ 17,004	Management of Integrated Manufacturing Systems.
	Dokainish, M.	Design	\$ 149,142	Software Optimization of CIM Procedures.
	Newcombe, W.	Design	<u>\$ 55,997</u>	Integration of Design of Jigs and Fixtures into Design/Mfg. Proc.
		TOTAL:	<u>\$1,469,651</u>	
3) <b>Queen's</b>	Browse, R.	Automation	\$ 48,093	Integrated Tactile and Visual Perception for Robots.
	Lederman, S.	Automation	\$ 47,197	Designing an Intelligent Tactual Perception System for Sensate Robotics Application of Models of Human Tactual Exploration and Recognition of Objects.

**APPENDIX 3 cont'd**

	Bayoumi, M.	Automation	\$ 99,783	Distributed Multisensory Multiprocessor Ctrl. Hierarchy Algorithms.
		TOTAL:	<u>\$ 195,073</u>	
4) <b>Carleton</b>	Goldak, J.	Design	\$ 193,084	Feature-Based Design of Castings.
		TOTAL:	<u>\$ 193,084</u>	
5) <b>Waterloo</b>	Wong, A.	Automation	\$ 379,440	Sensor Knowledge-Based Intelligent Manufacturing.
	Vidyasagar, M.	Automation	\$ 172,955	Design/Ctrl. of Lightweight Robots/Off-line Optimal Path Planning.
	Kerr, H.	Automation	\$ 14,897	Constrained Robotics Welding Automation.
	Wilson, W.	Automation	\$ 51,538	Sensor Integration for Direct End-Point Ctrl. of Robot Manipulators.
	Vannelli, A.	Automation	\$ 28,656	Production Scheduling/Design for Assembly of Electronic Circuit Boards.
	Adams, K.	Automation	\$ 18,495	Ply Separation of Textiles.
	Ismail, F.	Processes	\$ 12,167	Detection of Vibration/Chattering.
	Martin, H.	Processes	\$ 42,038	Detection of Vibration/Chattering.
	Kerr, H.W.	Processes	\$ 159,948	Welding Automation.
	Sullivan, G.	Processes	\$ 248,209	Computer-Aided Process Engineering.
	Schey, J.	Processes	\$ 117,020	Tribological Aspect of Metal Forming.
	Lawless, J.	Management	\$ 51,522	Analysis/Ctrl. of Warranty Claims/Reliability Problems.
	Buzacott, J.	Management	\$ 241,500	Planning/Scheduling Under Uncertainty.

**APPENDIX 3 cont'd**

	Wu, C.F.J.	Management	\$ 52,116	Implementation/Analysis of Statistically Designed Experiments in Manufacturing.
	Yovanovich, M.	Design	\$ 265,786	Thermo Fluid CAD and Optimization for Integrated Mfg.
	Andrews, G.	Design	\$ 27,869	Integration of Solid Modelling Kinetic Dynamic Analysis.
	Pick, R.	Design	\$ 10,770	Dev. of Raster-Based CAD Algorithms for Drawing Mgmt. Systems.
		TOTAL:	<u>\$1,894,926</u>	
<hr/>				
6) <b>Toronto</b>	Davison, E.	Automation	\$ 143,891	Dev. of Control Techniques for Robotic Systems/Process Ctrl's.
	Smith, K.	Automation	\$ 118,885	Sensors and Sensor Emphasizing Preconditioning.
	Fenton, R.	Automation	\$ 71,619	Robot Structural/Deflection Analysis, Design, Optimization and Performance Evaluation.
	Benhabib, B.	Automation	\$ 112,877	An Experimental Automatic Workcell, and Analysis/Design of Industrial Robots.
	Goldenberg, A.	Automation	\$ 395,310	Uncertain Geometry in Off-line Robot Planning.
	Woodhams, R.	Processes	\$ 223,425	Mfg. of Ordered Polymeric Profiles by Extrusion Drawing.
	Sethi, S.	Management	\$ 127,924	Statistical Methods for Product Design.
	Turksen, I.	Management	\$ 142,432	Knowledge-based Management Systems for Integrated Mfg.
	Meguid, S.A.	Design	\$ 97,964	Software Optimization and Integration in CIM. Environment
		TOTAL:	<u>\$1,434,327</u>	

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## **APPENDIX 4**

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### **Financial Statements**

**Manufacturing Research Corporation of Ontario**

March 31, 1990

# AUDITORS' REPORT

## Ernst & Young

CHARTERED ACCOUNTANTS

P.O. Box 458  
305 King Street West  
Kitchener, Canada N2G 4A2

Tel: (519) 744-1171  
(519) 653-3290  
Fax: (519) 744-9604

To the Members of the  
**Manufacturing Research Corporation of Ontario**

We have examined the statement of financial position of the **Manufacturing Research Corporation of Ontario** as at March 31, 1990 and the statement of income and expenses and change in fund balance for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests and other procedures as we considered necessary in the circumstances.

In our opinion, these financial statements present fairly the financial position of the corporation as at March 31, 1990 and the results of its operations and the changes in its financial position for the year then ended in accordance with generally accepted accounting principles applied on a basis consistent with that of the preceding year.



Kitchener, Canada,  
June 18, 1990.

Chartered Accountants

**Manufacturing Research Corporation of Ontario**  
(Incorporated under the laws of Ontario)

**Statement of Financial Position**

As at March 31


	1990 \$	1989 \$
<b>ASSETS</b>		
Cash	12,908	4,400
Funds on deposit [note 3]	566,851	104,357
Accounts receivable	90,963	—
Due from University of Waterloo - interest	9,390	3,475
Due from Formtech Inc. [note 4]	41,520	—
Advances to researchers	102,402	418,111
Prepaid rent	1,907	1,907
Fixed assets [note 5]	3,019,502	2,015,935
	<u>3,845,443</u>	<u>2,548,185</u>

**LIABILITIES, EQUITY AND FUND BALANCES**

Accounts payable	238,637	35,772
Equity in fixed assets [note 5]	3,019,502	2,015,935
Fund balance	587,304	496,478
	<u>3,845,443</u>	<u>2,548,185</u>

*See accompanying notes*

On behalf of the Board:



J.E. Urbanic  
Director



E.A. Dyson  
Director

**Manufacturing Research Corporation of Ontario**

**Statement of Income, Expenses and Change in Fund Balance**

Year ended March 31

	1990 \$	1989 \$
<b>INCOME</b>		
Government grants [note 2]	6,024,000	5,587,900
Research contracts [note 7]	364,824	—
Interest income	132,987	50,398
	<u>6,521,811</u>	<u>5,638,298</u>
<b>EXPENSES</b>		
Salaries and benefits	2,743,942	2,101,446
Overhead	1,529,598	1,237,665
Direct operating	1,169,967	734,658
Capital	1,003,567	1,665,581
	<u>6,447,074</u>	<u>5,739,350</u>
Increase (decrease) in fund balance from operations	74,737	(101,052)
Increase in fund balance from Baden-Wurttemberg project [note 8]	16,089	—
Increase (decrease) in fund balance	<u>90,826</u>	<u>(101,052)</u>
Fund balance, beginning of year	<u>496,478</u>	<u>597,530</u>
Fund balance, end of year	<u><u>587,304</u></u>	<u><u>496,478</u></u>

*See accompanying notes*

## Notes to the Financial Statements

March 31, 1990

### 1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES AND REPORTING PRACTICES

The Manufacturing Research Corporation of Ontario ("the Centre") was incorporated on December 24, 1987 under the laws of Ontario as a not-for-profit corporation. The aim of the Centre is to foster long-term advanced research in manufacturing by universities and industry, and thus to enhance both knowledge and application of technology in order to help ensure the future research and industrial competitiveness of the Province of Ontario in a global context. This research is performed in a co-operative venture between post-secondary educational institutions and industry. The Centre is managed independently of the universities and industries which have created, and are participating in the work of the Centre.

In 1990 the Canadian Institute of Chartered Accountants required that non-profit organizations present their financial statements in accordance with generally accepted accounting principles. For the year ended March 31, 1990, the Centre conformed with this requirement and no significant changes to the financial statements resulted.

The following summarizes the significant policies followed by the Centre:

#### Fund accounting

The accounts of the Centre have been maintained in accordance with the principles of fund accounting in order that limitations and restrictions placed on the use of available resources may be observed.

#### Accrual accounting

The accrual basis of accounting is followed whereby research and other expenses are recorded when incurred, and revenues when collected or when collection is virtually certain.

#### Fixed assets

Equipment purchases are expensed in the period incurred.

The accumulated original cost of fixed assets, less any disposals, is recorded on the

statement of financial position; equity in fixed assets is recorded to the extent that asset acquisitions are currently funded or debt incurred to acquire such assets has been retired.

### 2. FUNDING OF THE CENTRE

The Province of Ontario is committed to make grants to the Centre of not more than \$31,000,000 over a period of five years on account of the program. The grants are to be provided quarterly, in accordance with the business plan submitted by the Centre. During the fiscal period ended March 31, 1990 the Centre received \$6,024,000.

Future funding from the Province of Ontario is contingent upon the Centre meeting certain criteria. Funding has been approved as follows:

	\$
Received to date	13,326,911
Subsequent funding schedule	
March 31, 1991	6,239,300
March 31, 1992	6,462,000
December 31, 1992	4,971,789
	17,673,089
	<u>31,000,000</u>

The amount of the unexpended portion of the Provincial grants which may be utilized in any subsequent operating period shall not exceed the following:

End of operating period	% of period allocation
3	10
4	5
5	5
6	0

### 3. FUNDS ON DEPOSIT

Funds on deposit are held by the University of Waterloo on behalf of the Centre. The University of Waterloo pays the Centre interest at the average monthly rate of return earned on the University's short-term investments.

### 4. MANAGEMENT CONTRACTS

The Centre manages the business affairs of Formtech Inc., an industry consortium formed to conduct research in the field of metal stamping. In return for this service the Centre is paid \$100,000 per annum which is reflected in revenue from research contracts. The banking activities of Formtech are conducted through the Centre which has resulted in a balance receivable from the company at the year-end. Formtech transactions are not otherwise recorded in the Centre's financial statements.

### 5. FIXED ASSETS

All equipment or other assets purchased with any part of the Provincial grants shall be the property of the Centre. Upon termination of the Centre or, if the agreement with the Government of Ontario is terminated prior to December 31, 1992, the ownership of the assets transfers to the Government of Ontario. Participants in the Centre shall have an option to acquire the assets at fair market value at that time.

### 6. CONTRACT RESEARCH - UNIVERSITIES

The Centre subcontracts research performed on its behalf to faculty members of the universities of Toronto, Western, Waterloo, McMaster, Queens and Carleton. Salaries expense represents administrative salaries, reimbursement to participating universities for the cost of incremental personnel directly involved and working in the research program of the Centre, and the costs to purchase release time from teaching duties in order to free additional time for personnel to dedicate to the program. Overhead is generally charged at a rate of 65% of salaries and benefits by the participating universities; such charge is meant to recover both the general university costs of the research program, and the incremental cost of providing general infrastructure support at the academic unit level. Academic units of the universities are required to utilize 24% of the overhead charge as a research grant for the enrichment of the Centre's research program.

### 7. RESEARCH CONTRACTS - INDUSTRY

The Centre enters into research contracts with the corporate sector including both individual companies and industry consortia. The revenues earned from this research are paid directly by industry.

### 8. BADEN-WURTTENBERG PROJECT

The Manufacturing Research Corporation of Ontario entered into an agreement with the Province of Ontario effective January 1, 1990 which states that the Province is to provide additional funding to the Manufacturing Research Corporation of Ontario in the amount of \$690,000 over a 3 year period. This funding is to be used for the Computer-Aided Process Planning/Production and Control Integration Project which has as its major objective in the improvement in the implementation of Computer Integrated Manufacturing. The research is to be conducted in conjunction with the Fraunhofer Institute for Production Automation of the State of Baden-Wurtemberg, West Germany. The agreement between the Fraunhofer Institute for Production Automation and the State of Baden-Wurtemberg is similar to the agreement between the Manufacturing Research Corporation of Ontario and the Province of Ontario and is for the same amount. Technology transfer will take place between the two companies, but no funds will be transferred.

Future funding from the Province of Ontario is contingent upon the Project meeting certain criteria. Funding has been approved as follows:

	\$
Receivable March 31, 1990	57,500
Subsequent funding schedule	
March 31, 1991	230,000
March 31, 1992	230,000
December 31, 1992	172,500
	<u>632,500</u>
	<u>690,000</u>

The increase in fund balance from Baden-Wurtemberg Project is determined as follows:

	\$
Income	
Government grants receivable	57,500
Expenses	
Salaries and benefits	24,822
Overhead	16,134
Direct operating	455
	<u>41,411</u>
Increase in fund balance from Baden-Wurtemberg Project	16,089

## 9. COMPARATIVE FIGURES

Certain of the comparative figures have been reclassified to conform with the presentation adopted in the current year.









1075 North Service Rd. W., Suite 201, Oakville, Ontario L6M 2G2